EXTINGUISHING FIRE WITH CARBON DIOXIDE IN THE VALIER MINE, VALIER COAL CO., VALIER, FRANKLIN COUNTY, ILL.

BY JAMES WESTFIELD, H. C. BRUMBAUGH, AND R. W. WHITTAKER

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by

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INTRODUCTION

The purpose of this circular is to describe the sealing off of a mine fire and subsequent use of carbon dioxide gas to extinguish it.

A fire of electrical origin occurred in the Valier mine of the Valier Coal Co., Valier, Franklin County, Ill., on March 29, 1949, at about 1:35 p.m. It was discovered about 3:35 p.m. in 5 south west intake airway inby 1 and 2 west panels. The No. 5 southwest airway had caved, and the fire was in the top coal beneath a large fall of rock. All men, except officials, were ordered from the mine. The mine officials decided to seal the fire, and four temporary seals were erected, which isolated approximately 200 feet of 5 south west entry. The seals were completed on March 30 at 2:45 a.m., but on March 31, at 3:40 a.m., two of them were blown out by an explosion of gas that was produced by the fire. The two seals were rebuilt, the work being completed on March 31 at 12:00 noon, but they were blown out by another gas explosion at 12:10 a.m. on April 1. It was then decided to extinguish the fire with water if possible.

To accomplish this, concrete-block dams were constructed. On April 1, about 4:25 a.m., when the dams were about half completed, water was introduced into the fire area through a 2-inch pipe.

On April 4, J. G. Crawford, general manager of the Valier Coal Co., notified James Westfield, chief of the Vincennes (Ind.) Branch, U. S. Bureau of Mines, by telephone of the fire in Valier mine and requested assistance to combat it. Westfield, accompanied by F. J. Smith and H. C. Brumbaugh, Federal coal-mine inspectors, went underground and inspected the seals and dams. Later, during a conference with company officials, it was decided that the concrete-block dams were not strong enough to withstand the hydrostatic pressure that would be produced by flooding the fire area. It was then decided to use carbon dioxide gas to extinguish the fire. Four seals were completed, and 5 tons of carbon dioxide gas was introduced into the fire area, which extinguished the fire.

ACKNOWLEDGMENT

The authors greatly appreciate assistance of the officials of the Valie Coal Co. and the representatives of the Cardox Corp. in the preparation of this circular.

GENERAL INFORMATION

The principal offices of the Valier Coal Co. are in Chicago, Ill. Valier mine is served by the Chicago, Burlington & Quincy Railroad.

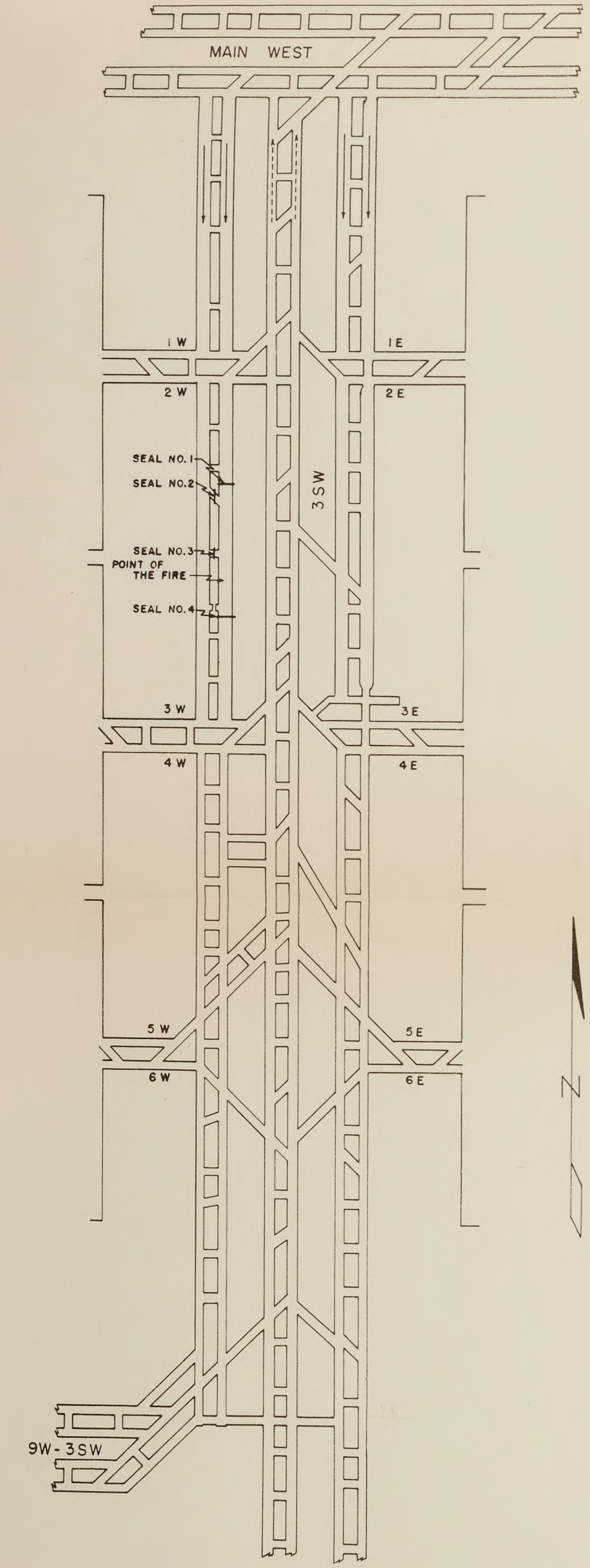

Figure 1. - Location of fire area.

The mine is opened by two concrete-lined shafts, one of which (the coal-hoisting shaft) is 596 feet deep and the other is 578 feet deep. The mine is developed in the Illinois No. 6 coal bed, which is flat and averages 8 feet in thickness. Six feet of the coal bed is mined, and 2 feet of top coal is not mined and forms the immediate roof. The main roof is laminated shale about 60 feet thick, and the bottom rock is hard fire clay. The cover ranges from 600 to 650 feet in depth. The average employment was 631 men, of which 542 worked underground and 89 worked on the surface on two shifts. The daily production averaged 6,150 tons of coal, all of which was loaded with mobile loading machines.

An adequate supply of water is piped to all sections of the mine through a 2-inch pipe line and is available for fire fighting. Fire hose, an ample supply of rock dust, and suitable fire extinguishers are provided at strategic places throughout the mine.

Several fires, thought to be of electrical origin, have occurred in this mine. Two large areas had been sealed before the fire described herein broke out. In one of them, considerable mining equipment was left behind the seals.

STORY OF THE FIRE

At 1:35 p.m. on March 29, 1949, an electrical power failure occurred in the 9 west south and the main south, and because of the possibility of fire, all employees except those engaged in finding the cause of the power failure were ordered to leave the mine.

Smoke was observed in 5 south west intake airway at about 3:35 p.m., and the fire was discovered therein between 2 and 3 west panels about 800 feet inby the junction with main west. The fire was in a caved area, and it was decided that the top coal beneath the "fall" was burning.

The mine officials decided to seal the fire by erecting four temporary wooden seals - two in 5 south west entry and one in each of the two crosscuts between the 5 and 6 south west entries (fig. 1). The sealed area comprised 200 feet of 5 south west entry that was approximately 24 feet wide and was originally driven to a height of 6 feet. The entry caved to a height of 20 to 40 feet for almost the entire length of the sealed area. The temporary seals were completed at 2:45 a.m. on March 30.

At 3:40 a.m. on March 31, about 25 hours after the seals were completed, the north and south seals were blown out by an explosion of gas that was ignited by the fire. The seals were rebuilt, the work being completed at noon on March 31, but at 12:10 a.m. on April 1, about 12 hours later, the north and south seals were again blown out by an explosion of gas.

The mine officials then decided to extinguish the fire with water, if possible. Concrete-block dams were constructed so that water could be introduced into the fire area. At 4:25 a.m. April 1, when the dams were about half completed, water was introduced into the fire area through a 2-inch pipe.

On April 4, J. G. Crawford, general manager of the Valier Coal Co., notified the Vincennes, Ind., office of the Bureau of Mines by telephone that a fire was burning in the Valier mine and requested assistance to combat it. On April 5, James Westfield, F. J. Smith, and H. C. Brumbaugh, of the Bureau of Mines, went underground to inspect the construction of the seals and dams. After the inspection, during a conference with company officials, it was decided that the concrete-block dams would not withstand the hydrostatic pressure that would result from flooding the entire fire area. It was then decided to use carbon dioxide gas to extinguish the fire.

An official of the Valier Coal Co., through a representative of the Cardox Corp. at Benton, Ill., arranged for delivery of 5 tons of liquid carbon dioxide, which arrived at the mine in a tank mounted on a trailer truck. A converter to gasify liquid carbon dioxide was part of the equipment installed on the trailer truck.

Concrete-block seals were completed at 10:00 a.m. on April 6, whereupon the mine officials discontinued piping water into the fire area. The water behind the seals had reached a maximum height of 40 inches above the bottom of the south seal. Large volumes of smoke were issuing from the fire area indicating that the fire had not been extinguished; moreover the south seal was being heated.

The possibility of an explosion constitutes an ever-present hazard during sealing operations after a fire area has been sealed and until the oxygen content of that part of the atmosphere surrounding the active fire is reduced to less than the critical oxygen value of the air-free original atmosphere.3/ This statement is substantiated by the fact that the north and south seals were blown out twice.

To prevent the seals from being blown out, it was decided to ventilate the area during the early stages of admitting the diluent (carbon dioxide gas) into the area, so that the diluent therein could be increased to a point where the atmosphere could not form an explosive mixture during and after the sealing operations.

Wooden trapdoors 24 x 30 inches were built in both the north and south seals. A 2-inch pipe equipped with a gate valve was installed in the north seal, and two 2-inch pipes equipped with valves were installed in the south seals.

The carbon dioxide gas was admitted into the fire area for the first time at 11:30 a.m. on April 6, and the man doors in the north and south seals remained open. The ventilating currents were directed through the fire area until 12:50 p.m. April 6, at which time the carbon dioxide content of the atmosphere returning from the fire area had increased to 40 percent, and it was decided that the atmosphere was not capable of forming an explosive mixture. The two doors in the seals were then closed.

3/ Ash, S. H., and Felegy, E. W., Analyses of Complex Mixtures of Gas: Bureau of Mines Bull. 471, 1948, p. 81.

It is interesting to note that this procedure was not necessary, because the critical gas-mixture value, as calculated from the four samples taken prior to introduction of the carbon dioxide gas, showed that the atmosphere was not explosive or capable of forming an explosive mixture.

The partial flooding apparently had decreased the amount of burning material, because the atmosphere from the fire area had produced an explosive mixture on two previous occasions - March 31 and April 1.

Ash and Felegy[4] developed a method of determining whether or not an atmosphere containing combustible gas was capable of forming an explosive mixture. This is done by determining the critical gas-mixture value of the air-free original atmosphere; consequently, the constituents of the original atmosphere are calculated on an air-free basis.

Table 1 gives the analyses of four samples taken in the fire area prior to the introduction of carbon dioxide gas, and table 2 gives the analyses calculated to an air-free basis. When these samples were taken, the fire seals were not completed, and ventilation was maintained over the fire area.

TABLE 1. - Analyses of mine air samples taken prior to the introduction of CO_2 gas into fire area of Valier mine

Bottle No.	Percent in volume							Date	Time, a.m.
	CO_2	O_2	Air	H_2	CO	CH_4	N_2		
3053 ...	0.81	20.02	95.65	0.07	0.06	0.20	78.84	4/5/49	11:30
8858 ...	1.78	18.72	89.44	.20	.20	.22	78.88	4/5/49	11:32
5675 ...	4.84	15.04	71.86	.44	.50	.39	78.79	4/5/49	11:42
4654 ...	6.59	12.86	61.44	.57	.65	.48	78.85	4/5/49	11:40

TABLE 2. - Constituents of original atmosphere calculated on an air-free basis (samples taken prior to introduction of CO_2 into fire area of Valier mine.)

Sample No.	$(H_2)_1$ H_2	B_1 CH_4	A_1 CO	N_2	D_1 CO_2	Total constituents
3053	1.61	4.60	1.38	73.79	18.62	100
8858	1.89	2.08	1.89	77.28	16.86	100
5675	1.56	1.39	1.78	78.07	17.20	100
4654	1.48	1.24	1.69	78.50	17.09	100

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[4] Ash, S. H., and Felegy, E. W., Analyses of Complex Mixtures of Gases: Bureau of Mines Bull. 471, 1948, pp. 19, 22, 90-93, and 197.

CALCULATIONS OF THE CRITICAL GAS-MIXTURE VALUE

The critical gas-mixture values were determined for the four samples as follows:

Applying the critical gas-mixture value method to sample 3053, it was first determined that $(10.2\ H_2) < CO_2$ (in the air-free analysis).

$10.2 \times 1.61 = 16.42$ and is $< (CO_2)$ or 18.62.

Then:

$$C.\ G.\ M.\ V._{N_2} = \frac{10{,}000}{5.15A_1 + 7B_1 + 20.12\ (H_2)_1 - 0.875D_1}$$

wherein $C.\ G.\ M.\ V._{N_2}$ is the critical gas-mixture value (in percent) of the air-free original atmosphere:

A_1 = the volume of carbon monoxide in the air-free original atmosphere

B_1 = the volume of methane

$(H_2)_1$ = the volume of hydrogen

and

D_1 = the volume of carbon dioxide

$$= \frac{10{,}000}{(5.15 \times 1.38)+(7 \times 4.60)+(20.12 \times 1.61)-(0.875 \times 18.62)}$$

$$= \frac{10{,}000}{7.107 + 32.2 + 32.3932 - 16.2925} = \frac{10{,}000}{55.41} = 180.47$$

The critical gas-mixture values calculated for the three remaining samples are as follows:

Sample 8858 - $C.\ G.\ M.\ V._{N_2} = 212.91$

Sample 8575 - $C.\ G.\ M.\ V._{N_2} = 283.82$

Sample 4654 - $C.\ G.\ M.\ V._{N_2} = 310.49$

The critical gas-mixture value was calculated with nitrogen as the diluent rather than carbon dioxide. It is immaterial which formula is used to calculate the critical gas-mixture value of the air-free mixture insofar as selection according to the inert gas (diluent) is concerned. It is necessary only to select the pertinent case and use the pertinent formula as determined by the relationship between the volume of hydrogen and carbon dioxide, carbon monoxide and nitrogen, or methane and nitrogen.

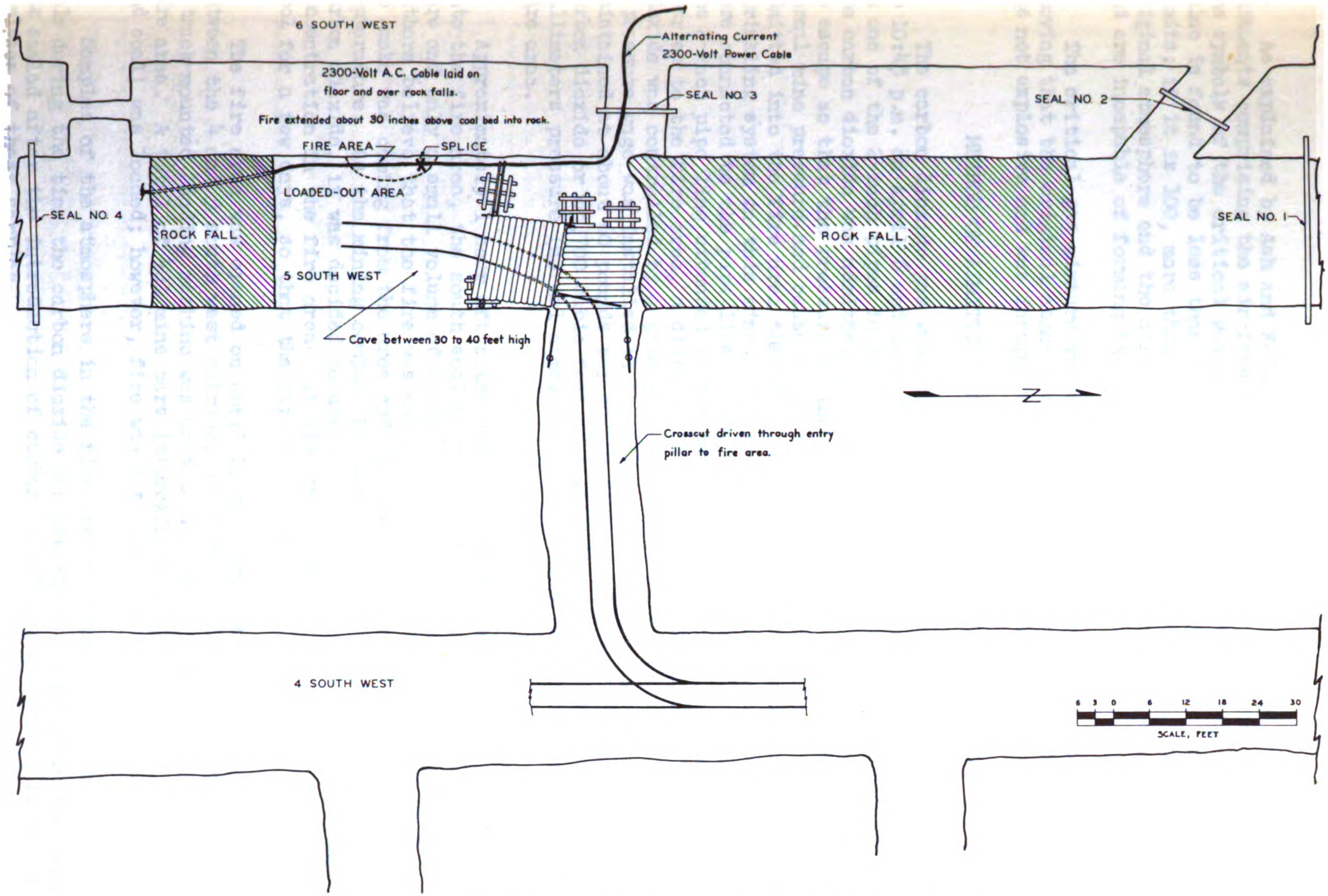

Figure 2. - Timbering and track used to load out fire area.

As explained by Ash and Felegy, if the real value of the various constituents comprising the air-free original atmosphere are substituted for the symbols of the critical gas-mixture formula, and the critical gas-mixture value is found to be less than 100, the air-free analysis has explosive limits; if it is 100, more than 100, or has a negative value, both the original atmosphere and the air-free original atmosphere are not explosive and are incapable of forming explosive mixtures with air.

The critical gas-mixture value of the four samples is greater than 100, showing that the original atmosphere of the air-free original atmosphere was not explosive and was incapable of forming an explosive mixture with air.

METHOD OF ADMITTING CARBON DIOXIDE INTO THE FIRE AREA

The carbon dioxide gas was admitted into the fire area from 11:30 a.m. to 10:45 p.m. on April 6 and from 9:00 to 11:30 a.m. on April 7. A valve in one of the 2-inch pipes in the south seal was open during the period that the carbon dioxide was admitted into the fire area to allow the gas therefrom to escape so that the pressure in the fire area would not increase above the normal mine pressure and cause leaky seals. The carbon dioxide gas was admitted into the fire area through a 2-inch pipe line, which was part of the sprinkling system in this mine. The liquid carbon-dioxide tank and converter were connected to the pipe line at the top of the material and man shaft. The 2-inch pipe line extended to the bottom of the shaft and along the haulage entries to the fire area, a distance of 7,000 feet. The flow of carbon dioxide was controlled by a gate valve installed in the line on the surface. A pressure gage was installed in the pipe line, and the line pressure was maintained at about 60 pounds per square inch. A total of 5 tons of liquid carbon dioxide or 85,700 cubic feet of carbon dioxide gas at 60° F. and 760 millimeters pressure (normal atmospheric conditions) was introduced into the fire area.

Approximately 1 hour after the carbon dioxide gas was first introduced into the fire area, the south seal had cooled to almost normal mine temperature and only a small volume of smoke was issuing from the fire area. The authors believe that the fire was extinguished by 10:00 p.m. on April 6, as no smoke was coming from the area and the seals had cooled to normal mine temperature. As the mining company had contracted to purchase 5 tons of carbon dioxide, it was decided to use the entire amount to maintain a high concentration in the fire area. It also was decided to let the sealed area cool for a few days, so that the fire would not rekindle.

The fire area was opened on April 19 by driving through the pillars between the 4 and 5 south west entries, as shown in figure 2, after which a track-mounted loading machine was used to load rock and top coal in the fire area. A total of 421 mine cars (approximately 2,060 tons of rock, coke, and coal) was loaded; however, fire was not observed at that time.

Samples of the atmosphere in the fire area were taken at regular intervals during the time the carbon dioxide gas was admitted and while the area was sealed after the introduction of carbon dioxide gas. Table 3 gives the analyses of these samples.

TABLE 3. - Analyses of air samples taken during the introduction of CO_2 and while fire area was sealed in Valier mine

Bottle No.	Percent in volume						Date	Hour	Remarks
	CO_2	O_2	H_2	CO	CH_4	N_2			
3524	0.84	20.35	0.00	0.03	0.07	78.71	4/6/49	11:50 a.m.	Started admitting CO_2 into fire area at 11:30 a.m. Man doors open in north and south seals. Two 2-inch pipes open in south seal. Reduced ventilation in fire area.
6036	8.2	15.0	.0	.6	.4	75.8	4/6/49	11:55 a.m.	
8038	.72	20.56	.0	.10	.04	78.58	4/6/49	12:40 p.m.	
5875	39.5	6.8	.0	1.2	.8	51.7	4/6/49	12:45 p.m.	Closed one 2-inch pipe south seal 12:50 p.m. Closed man doors in north and south seals 12:50 p.m.
5095	49.4	5.0	1.2	1.6	.5	42.3	4/6/49	1:45 p.m.	
5555	55.6	4.9	1.1	1.9	.3	36.2	4/6.49	2:15 p.m.	
5055	69.1	2.4	.0	2.0	1.4	25.1	4/6/49	2:50 p.m.	
879-Y	64.2	4.5	.5	.9	.5	29.4	4/6/49	7:00 p.m.	
3574	73.7	1.6	.2	.7	.7	23.1	4/6/49	10:00 p.m.	Discontinued the use of CO_2 at 10:45 p.m.
1851	73.5	1.5	.6	.7	.5	23.2	4/7/49	10:00 a.m.	Started feeding CO_2 into sealed area again at 9:00 a.m.
5645	73.0	2.5	.0	1.0	.8	22.7	4/7/49	11:15 a.m.	
5795	73.6	1.8	.0	.9	.9	22.8	4/7/49	11:50 a.m.	All vent pipes closed. Discontinued use of CO_2 at 11:30 a.m.
3853	44.7	4.5	.2	.6	.6	49.4	4/11/49	9:00 a.m.	
4955	48.9	3.1	.0	.6	.7	46.7	4/11/49	9:10 a.m.	
5015	47.5	3.2	.4	.9	.6	47.4	4/11/49	9:00 p.m.	
2232	45.1	3.5		1.1	.8	49.5	4/12/49	10:30 a.m.	
4514	44.7	3.5		.8	.8	50.2	4/12/49	4:30 p.m.	
9989	36.2	6.6		.7	.8	55.7	4/13/49	10:15 a.m.	
5416	41.6	3.6		.6	.8	53.4	4/13/49	5:30 p.m.	
0630	39.9	3.5		.9	.8	54.9	4/14/49	10:30 a.m.	
6856	39.2	4.2		.3	.8	55.5	4/14/49	6:20 p.m.	
2132	37.7	4.2		.8	.8	56.5	4/15/49	9:40 a.m.	
5655	36.8	4.7		.3	.8	57.4	4/15/49	5:00 p.m.	
9299	29.0	7.6		.5	.7	62.2	4/16/49	10:45 a.m.	
1631	35.0	5.1		.5	.7	58.7	4/16/49	4:30 p.m.	
9639	33.9	5.4		.6	.7	59.4	4/17/49	9:30 a.m.	
1171	32.6	5.2		.23	.9	61.07	4/18/49	4:15 p.m.	

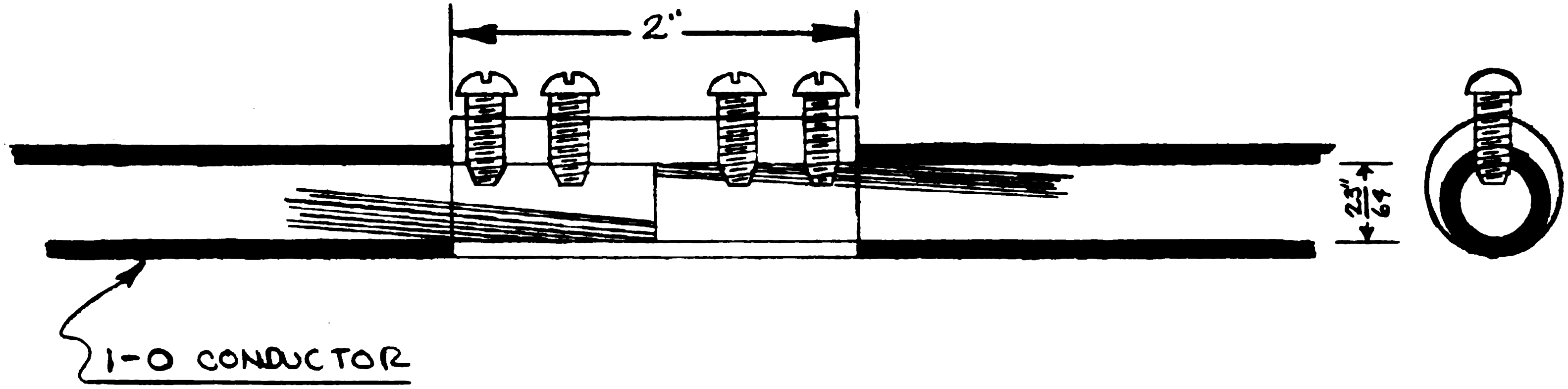

Figure 3. - 0-B two-way connector used for connecting high-tension rubber-covered cable.

The highest percentage of carbon dioxide in the fire area, sample 3574, was shown at 10:00 p.m. on April 6. Analysis of this sample shows that the carbon dioxide was 73.7 percent and the nitrogen 23.1 percent, a total of 96.8 percent inert gas. The oxygen content was 1.6 percent, and the combustible gases were 0.2 percent hydrogen, 0.7 percent carbon monoxide, and 0.7 percent methane.

The last sample, taken on April 18 just prior to opening the sealed area, showed 32.6 percent carbon dioxide and 61.07 percent nitrogen, a total of 93.67 percent inert gas. The oxygen content was 5.2 percent, and the combustible gases were 0.23 percent carbon monoxide and 0.9 percent methane.

INFORMATION OBTAINED DURING OPENING OF FIRE AREA

The following facts were disclosed during removal of rock from the fire area:

1. The fire had been extinguished by the carbon dioxide.

2. The fire was confined to an area of about 15 feet horizontally and 10-1/2 feet vertically; it had started in the top coal, which had fallen, and had extended into the carbonaceous shale overlying the coal bed. (See fig. 2)

3. The fire was of electrical origin. A 2,300-volt cable on the floor in the fire area was covered by a large fall of coal and rock. In cleaning up the fall, it was found that the cable had been spliced; however, the splice was made with small brass sleeve connectors, as shown in figure 3. The ends of the cable were "butted together" in a sleeve and held in place with four small set screws. The exposed wires and brass sleeves were then covered with rubber, cambric, and friction tape. Evidence found while the rock fall was being removed revealed that the insulation on the splice had been damaged by the fall, which, it is believed, resulted in a comparatively high-resistance short circuit between two of the cable connections. When the insulation burned from the cable connections, a "dead short" occurred, which caused enough current to flow to open the breaker at the 33,000-volt switching station. When the short circuit, which caused the fire, occurred, the breaker at the borehole did not open, because the overload "trip" was set for too high a current.

SUMMARY AND CONCLUSIONS

1. Attempts made by the company to seal the fire area were unsuccessful, because twice the seals were blown out by an explosion in the fire area.

2. The company attempted to flood the fire area with water, but this had to be discontinued because the dams were not strong enough to withstand the hydrostatic pressure that would result from flooding the area to the height of the caves, which was 20 to 40 feet.

3. Carbon dioxide gas was introduced into the fire area to dilute the mine-fire gases and extinguished the fire. Approximately 1 hour after the carbon dioxide was introduced into the fire area the south seal had cooled

to almost normal mine temperature, and only a small volume of smoke issued from the fire. The authors believe the fire was extinguished by 10:00 p.m. on April 6, approximately 11 hours after the carbon dioxide was first admitted to the area.

4. The use of carbon dioxide gas can prevent an explosion during sealing of a mine fire.

To avert recurrence of such a fire, the management plans to install a ground-fault protective system and has ordered the necessary material. The system will consist primarily of deriving a neutral from the delta-connected secondary at the borehole transformer station by using a zig-zag-connected grounding transformer. The neutral of this system then will be grounded through a current-limiting resistor. The 2,300-volt cables that supply the underground equipment will contain three grounding conductors and a metallic woven shield around each current-carrying conductor. The shield and grounding conductors will be connected and tied to the grounded neutral at the transformer station on the ground side of the resistor. In such a plan, when a cable is damaged mechanically, such as by a roof fall, the neutral circuit will be energized before a short circuit between conductors can occur. Also, the current flow in the neutral circuit will be limited by the resistor to a harmless value. The system also will be equipped with a fault-current tripping device, which will open the oil circuit breaker at the transformer station on the occurrence of a phase-to-neutral fault.